Lessons Learned from CERES

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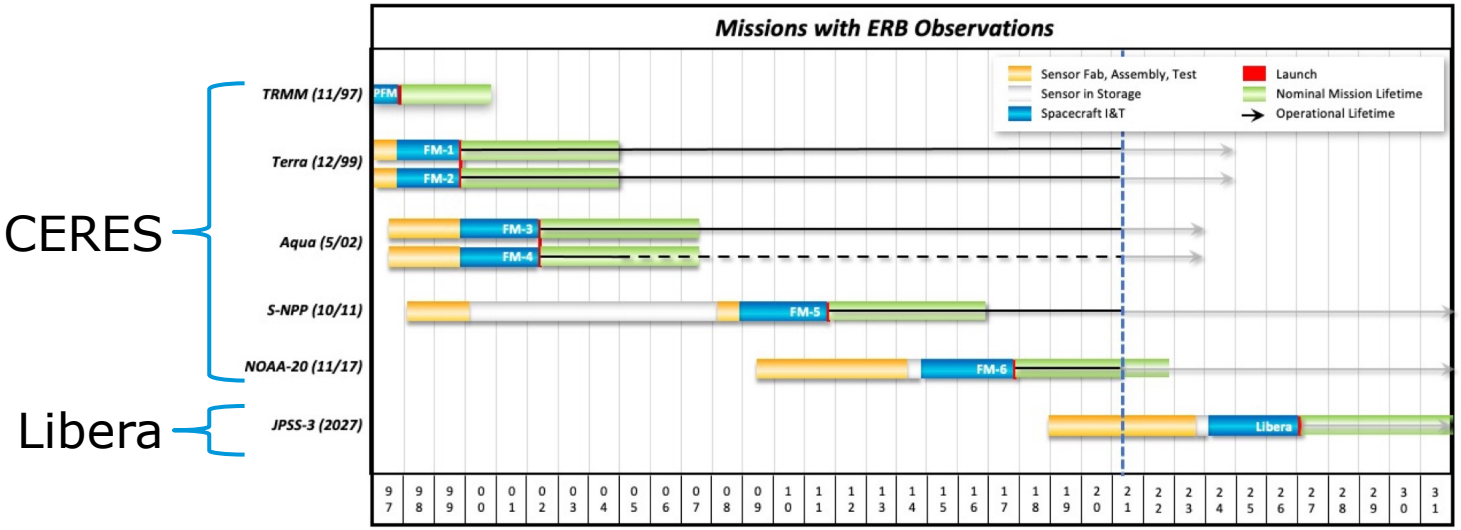
Lessons Learned From CERES

Radiation Budget Science Project Supported Missions



- Currently, 6 CERES instruments fly on 4 satellites: Terra (L1999), Aqua (L2002), SNPP(L2011), NOAA-20 (L2017)

Radiometric Performance Requirements

CERES is defined as a class 'B' Instrument

5-year design Lifetime

Spectral Regions	Reflected Solar		Emitted Thermal		Atmospheric Window
Wavelengths	0.3 - 5.0 μm		5.0 - 200 μm		8 - 12 μm
Scene levels	<100 w/m^2-sr	>100 w/m^2-sr	<100 w/m^2-sr	>100 w/m^2-sr	All Levels
Accuracy Requirements	0.8 w/m^2-sr	1.0 %	0.8 w/m^2-sr	0.5 %	0.3 w/m^2-sr
SOW Stability Requirements		< 0.14%/yr		< 0.1%/yr	
Climate Stability Goals		< 0.6 w/m^2/dec < 0.03 %/yr		< 0.2 w/m^2/dec < 0.02%/yr	

- **Requirements for CERES are more stringent than ERBE's by a factor of 2**
- **Requirements per Ohring et. al. are more stringent than CERES by a factor of 3-5**

Calibrate, Calibrate, Calibrate….

Evolve Observational Strategies via FSW Modifications

Why is ERB Climate Quality Calibration so difficult?

A question of time scales, experience and balancing accuracy with providing data products to the community.

- *Calibrated Radiances have been released on ~6 month centers*
- *6 months is just a blink of an eye when analyzing decadal trends…*

Same time scale as phenomena which influence instrument response

- *Beta Angle*
- *Solar Zenith Angle*
- *Earth Sun Distance*
- *Solar Cycle*
- *Orbital shifts*
- *Instrument Operational modes (e.g. RAPS vs. Xtrack)*

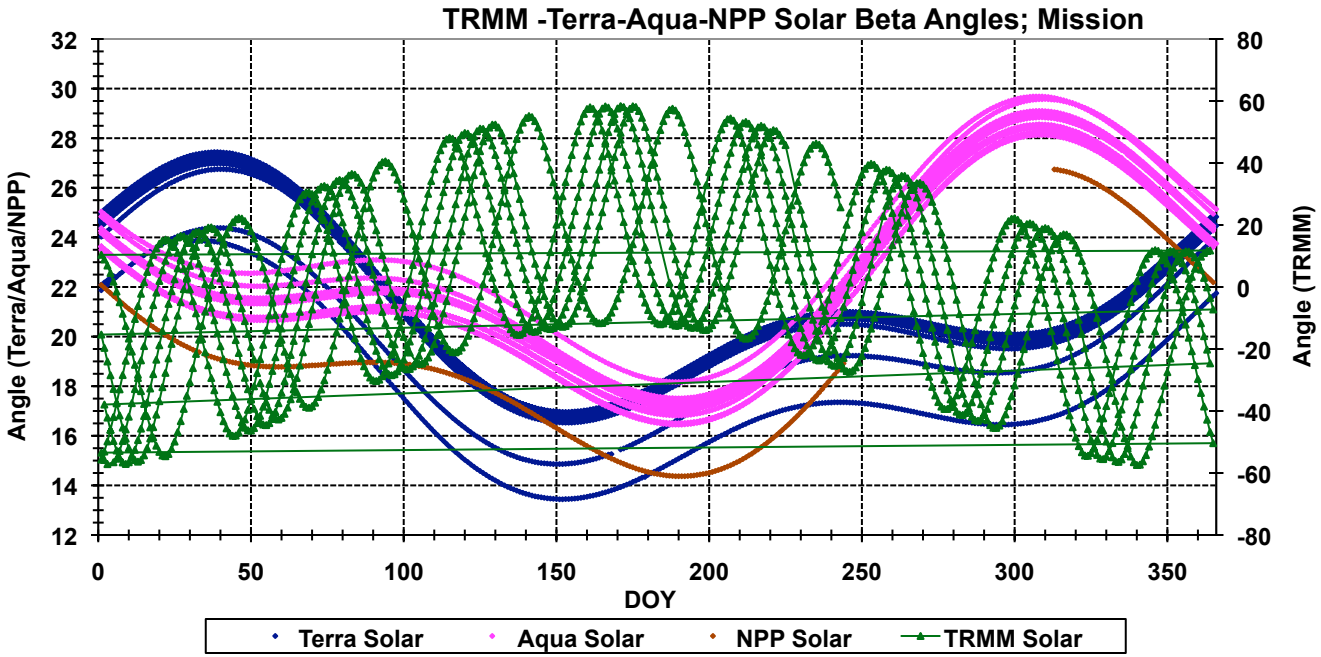
CERES is a Thermal instrument

Design weaknesses and unanticipated failures in onboard calibration hardware

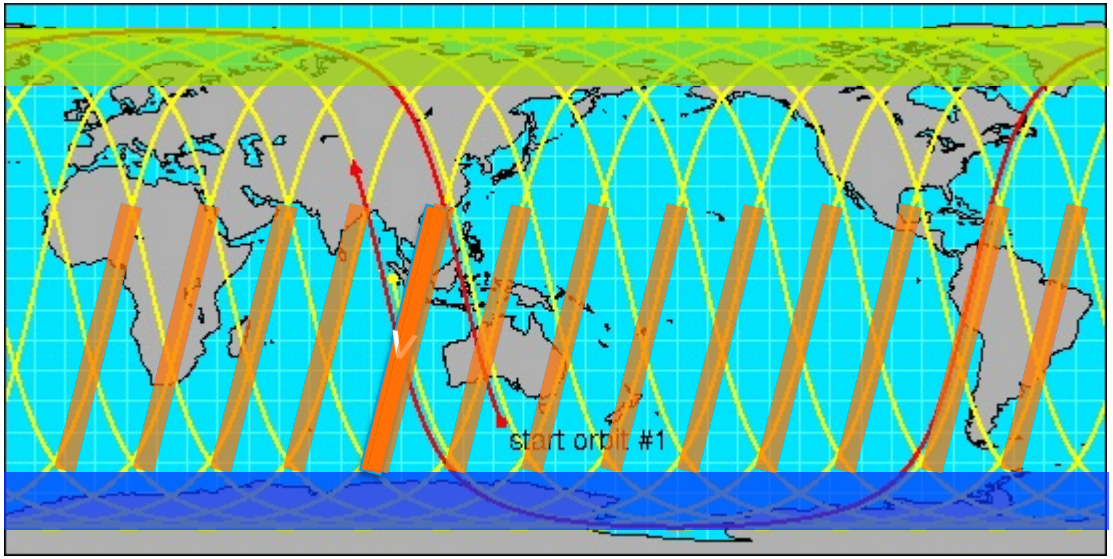
- *full spectral range of observations not covered by cal subsystems*

Complicates separation of instrument 'artifacts' from natural variability.

Beta Angle Annual Cycle

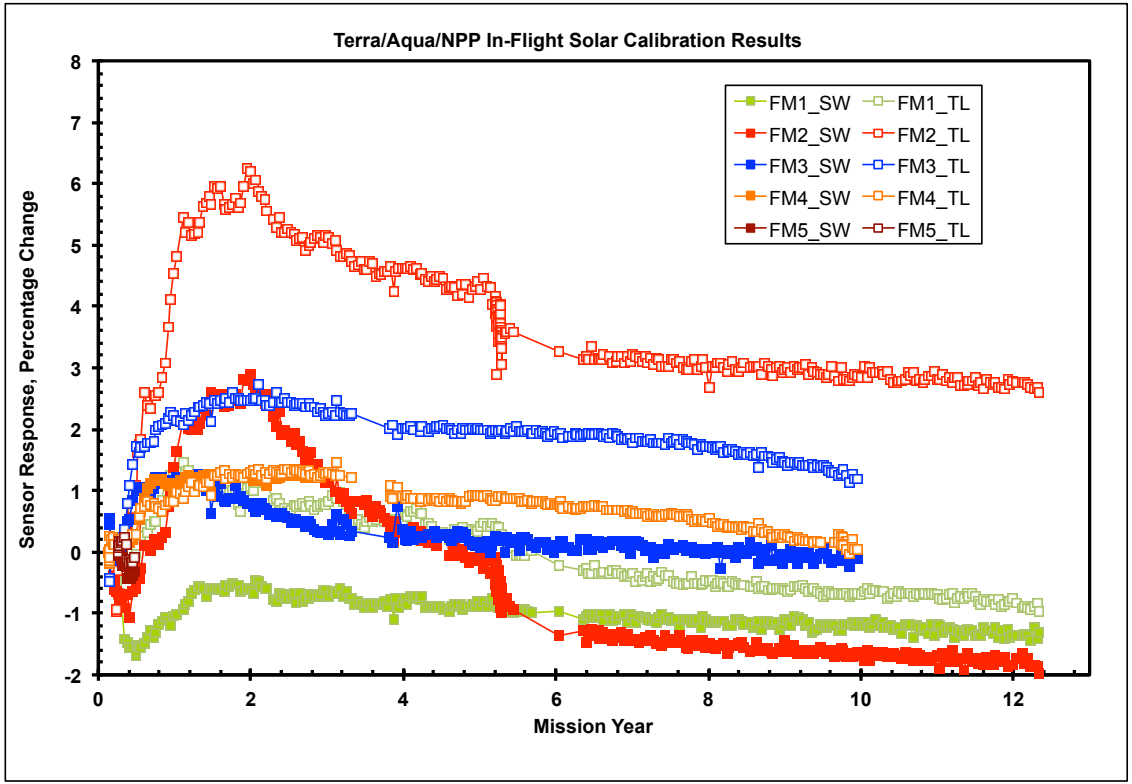


Aqua/NPP Flight Cal Locations



- Lunar Observations
- Solar Calibrations
- Internal Calibration Sequence

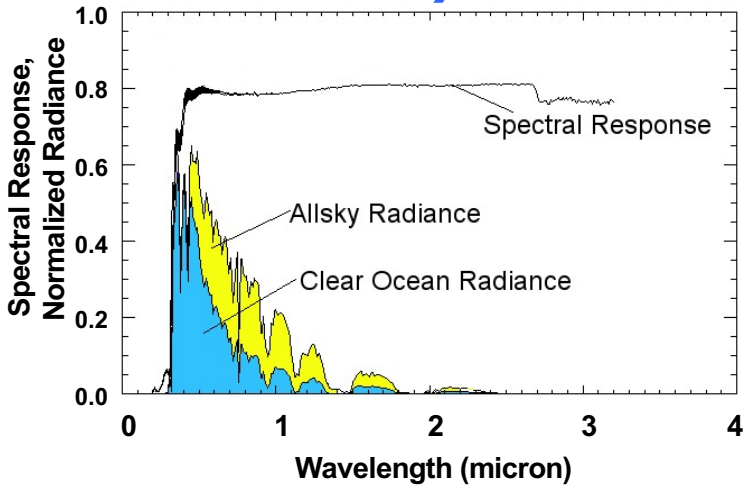
Solar Calibration Results

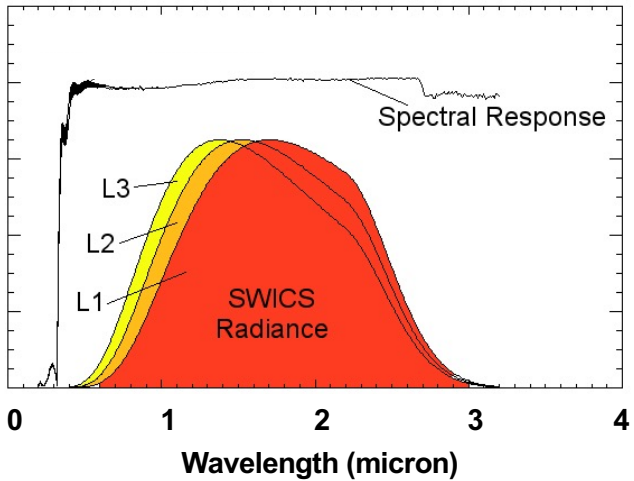


Si02 overcoat on the CERES FM1-FM4 Solar diffusers not applied properly, and continued to oxidize on orbit

Spectral Coverage of Cal Sources

Make certain the spectral content of your cal sources adequately represent the content of your science targets….





$$f^{sw}_{allsky} \text{ change} \approx -2\%$$

$$f^{sw}_{swics} \text{ change} \approx -0.1\%$$

Cal-Val Approach

Pre-Launch

- Implement a rigorous & thorough ground calibration/characterization program
- Cal/Val role must be prominent in original proposal and SOW
- System level characterization is typically last test performed prior to delivery of the instrument
- Cost and schedule constraints typically drive programs at that point

Post-Launch

- Implement a protocol of independent studies to characterize on-orbit performance
- Studies should cover all spectral, spatial and temporal scales as well as data product levels
- Continuous development of new validation studies

Data Product Release Strategy

- Develop a logical and well understood approach to data release.
- Minimize the number of Editions/Versions of Data
- Utilize Data Quality Summaries for the community

CERES Flight Radiometric Validation Activities

Clouds and the Earth's Radiant Energy System

		Product	Spatial Scale	Temporal Scale	Metric	Spectral Band
On-Board	Internal BB	Filtered Radiance	N/A	N/A	Absolute Stability	TOT, WN
	Internal Lamp	Filtered Radiance	N/A	N/A	Absolute Stability	SW
	Solar	Filtered Radiance	N/A	N/A	Relative Stability	TOT, SW
Vicarious	Theoretical Line-by-Line	Filtered Radiance	> 20 Km	Instantaneous	Inter-Channel Theoretical Agreement	TOT, WN
	Unfiltering Algorithm Theoretical Validation	N/A	N/A	N/A	N/A	TOT, SW, WN
	Inter-satellite (Direct Comparison)	Unfiltered Radiance	1-deg Grid	1 per crossing	Inter-Instrument Agreement, Stability	TOT, SW, WN
	Globally Matched Pixels (Direct Comparison)	Unfiltered Radiance	Pixel to Pixel	Daily	Inter-Instrument Agreement	TOT, SW, WN
	Tropical Mean (Geographical Average)	Unfiltered Radiance	20N – 20S	Monthly	Inter-Channel Agreement, Stability	TOT, WN
	DCC Albedo	Unfiltered Radiance	>40 Km	Monthly	Inter-Instrument agreement, Stability	SW
	DCC 3-channel	Unfiltered Radiance	>100 Km	Monthly	Inter-Channel consistency, stability	TOT, SW
	TIme Space Averaging	Fluxes	Global	Monthly	Inter-Instrument Agreement	LW, SW
	Lunar Radiance Measurements	Filtered Radiance	Sub Pixel	Quarterly	Inter-Instrument Agreement	LW, SW, WN

Lessons Learned / Future Direction

Programmatic Implementation

- Increase weighting/influence of Radiometric Performance in cost/schedule trades
- Maintain positive/open relationship with hardware provider. Avoid 'Us' vs. 'Them' mentality.
- *LaRC/NGST Team has proven track-record and experience*

Ground Characterization Procedures

- Re-verify traceability of calibration targets
- Establish collaborations with NIST, other international agencies
- Implement automated Data Acquisition System on Calibration Chamber

Operational Mode

- Do not point optics in 'forward' looking direction
- *Strong Correlation to spectral darkening of SW channel optics*

Onboard Calibration Hardware

- Provide additional SW spectral characterization capability
- *Stringent measurement requirements demand SW spectral capabilities*

Handling Procedures

- Minimize possibility of contamination
- Develop Inspection and cleaning procedures

Lessons Learned

- Establish a calibration team early and hold regular reviews/TIMS
- Understand that the Science team has Lifecycle responsibility
- Part science, part engineering, a lot of socialization
- Understand requirement traceability
- Be adept at responding to change
- Be robust to withstand unknowns/change
- Keep it simple
- Don't be afraid to evolve with technology
- Don't let Process replace sound judgment
- Engineer knows long before the statistician
- The only thing that is for certain is that if you don't try, you won't get it